

SMD User's Guide

R.C. Fernow

Brookhaven National Laboratory

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The Solenoid Magnet Designer (SMD) is a Windows program for designing solenoid magnets. The program displays the coil configuration graphically, shows the magnetic field on-axis and shows the net forces on each coil. It also shows the location of the peak field and peak hoop stress in the coils. The current density in the coils is compared with the critical current for the given peak field in each coil. It can also display the force distribution inside the coils, a grid of the off-axis magnetic field, magnetic lines of force, or the Fourier components of the on-axis field. It also contains a built-in optimizer.

1. Starting and stopping the program

The program can be started from a DOS (command) window using the command

```
C:> smd
```

or

```
C:> smd file.prm
```

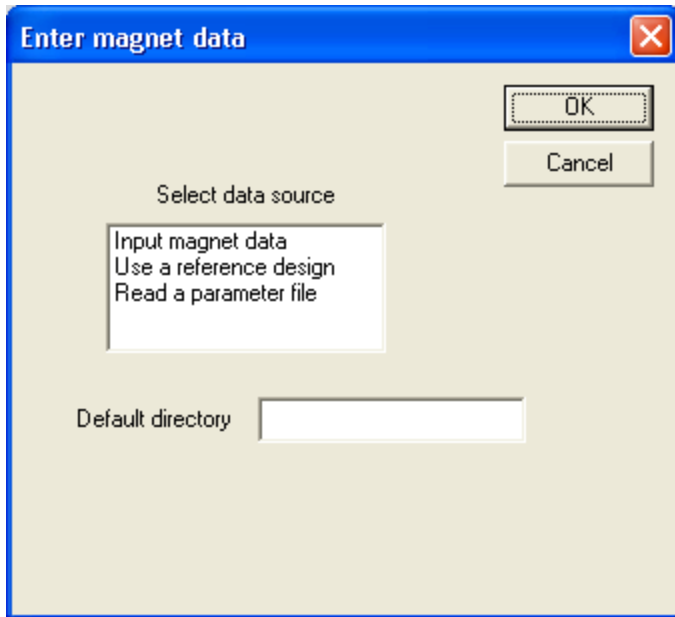
where *file.prm* is the name of an existing parameter file.

The program can also be started by clicking on its Windows icon.

If the **x** box in the upper right corner of the outer window is not visible, you can stop the program by selecting Exit in the File menu.

2. Opening screens

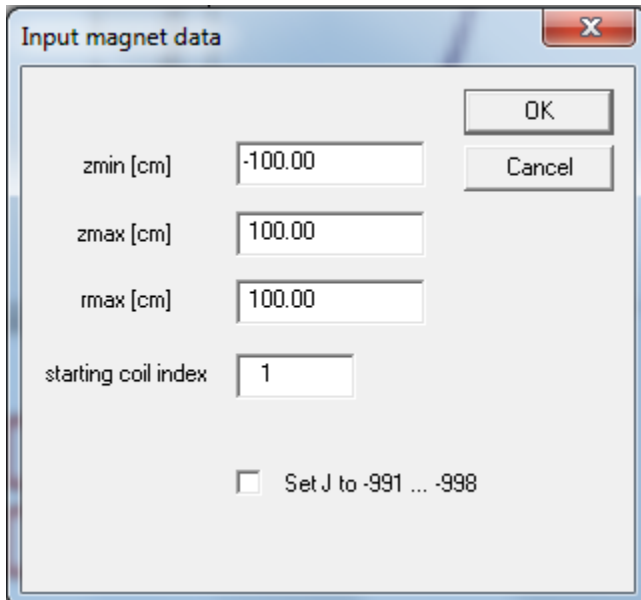
The figure shows the opening screen when the program is started without specifying a pre-existing parameter file.



The user has three choices to enter the magnet design data. The first choice allows inputting the data by filling out a set of dialog windows. The second choice brings up a list of built-in reference designs. The last choice is to read in an existing parameter file that has been previously saved or created offline. The directory for reading and writing files may also be changed here.

2.1 Entering data using the dialog windows

If the user chooses to input the data by hand, it brings up the window



The image shows a dialog box titled "Input magnet data" with a standard Windows-style title bar (blue with a red close button). Inside the dialog, there are four input fields arranged vertically on the left, each with a label and a text box. The labels are "zmin [cm]", "zmax [cm]", "rmax [cm]", and "starting coil index". The corresponding values in the text boxes are "-100.00", "100.00", "100.00", and "1". To the right of these fields are two buttons: "OK" and "Cancel". At the bottom of the dialog, there is a checkbox that is currently unchecked, followed by the text "Set J to -991 ... -998".

The quantities z_{min} and z_{max} are the axial limits for the geometry, on-axis field, and force plots. The quantity r_{max} is the maximum radius for these plots. The following dialog windows only allow changing parameters for 8 coils at a time. However, the starting coil index for 8 consecutive coils can be changed here. The check box at the bottom is used with the optimizer. If the box is checked, the current densities of the eight displayed coils are automatically chosen as the parameters to be varied. This can save some effort during the initial stages of optimization.

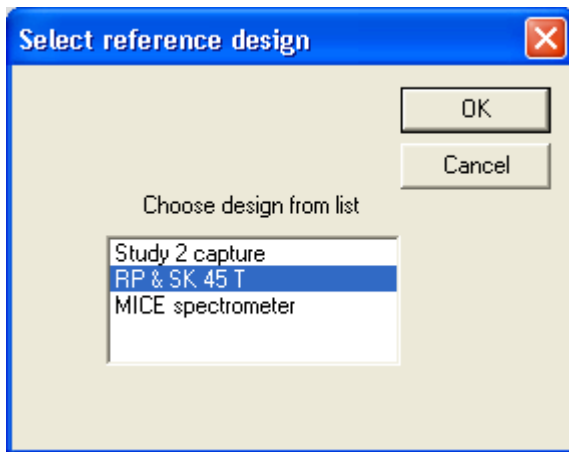
This is followed by a window to enter the coil parameters.

coil #	z_0 [cm]	L [cm]	a [cm]	t [cm]	J [A/mm ²]	SC material	Scale factor
1	-71.20	74.90	17.80	5.40	24.53	Cu	1.00
2	-71.20	87.70	23.20	12.20	19.20	Cu	1.00
3	-71.20	107.30	35.30	13.70	14.97	Cu	1.00
4	-125.30	178.10	63.60	64.20	23.54	Nb3Sn	1.00
5	62.80	72.90	68.60	32.50	25.48	Nb3Sn	1.00
6	145.70	99.90	77.60	21.20	29.73	Nb3Sn	1.00
7	255.60	155.00	77.60	10.70	38.26	Nb3Sn	1.00
8	420.60	185.90	77.60	6.56	42.84	Nb3Sn	1.00

The user sets the number of active coils in the box at the top. Then for each coil the user sets the starting axial position z_0 , the axial length L , the inner radius a , the radial thickness t , the engineering current density J , and the type of conductor. The last column is a current density scaling factor that multiplies the critical current for the material. The recognized superconductors are described in section 4. Up to 32 coils may be used in a design, but only the parameters of 8 coils at a time may be changed online.

2.2 Entering a reference design

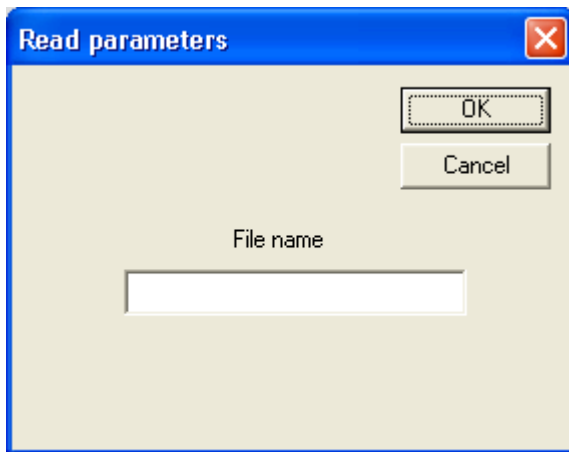
If the user chooses to enter a reference design it brings up the window.



The user should click on an item in the list.

2.3 Entering a saved design

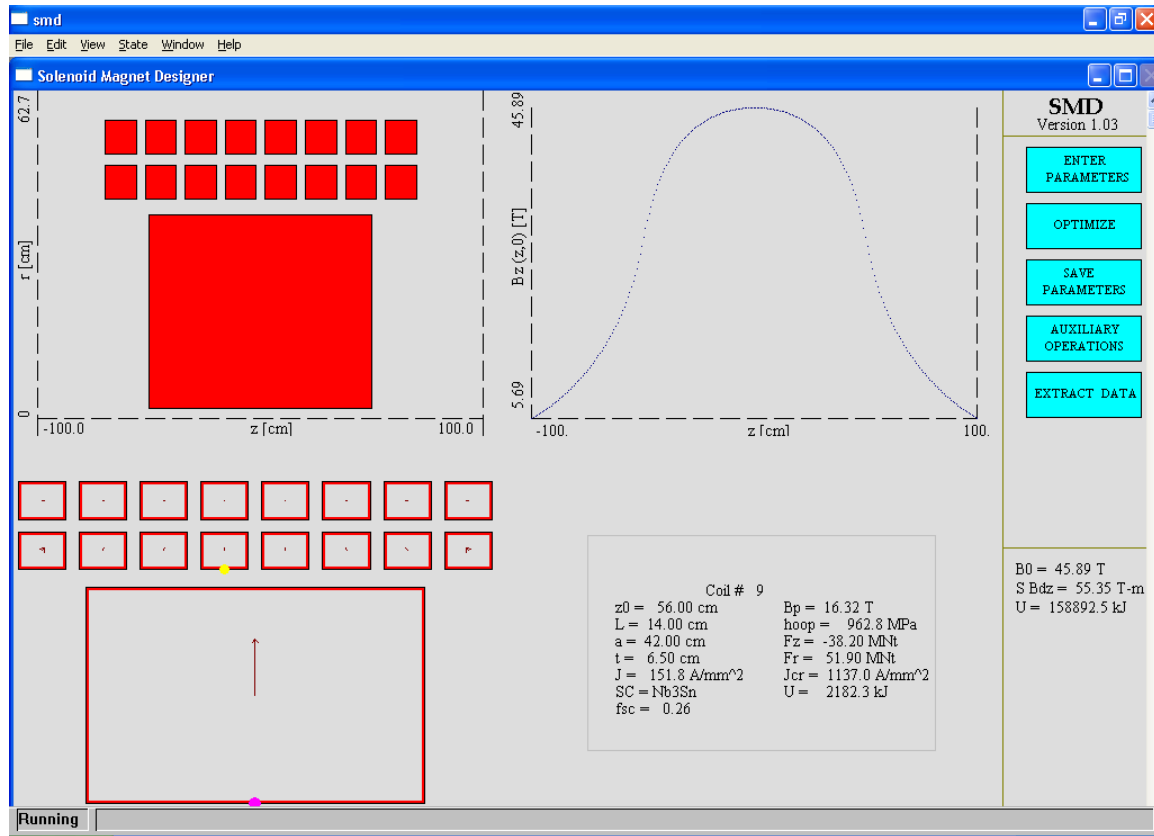
If the user chooses to enter a saved design it brings up the window.



The user should enter the filename of a previously saved design.

3. Results screen

After a design has been entered the program displays a screen similar to the following.



The upper-left graph shows the coil geometry. Coils with positive current are shown in red, while coils with negative current are shown in blue. Unfilled coils with black borders have 0 current, i.e. are turned off. The upper right graph shows the solenoidal field on-axis. The lower left graph shows a blow-up of the coils with the net force indicated on each coil. The magenta circle on the coil shows the peak field location. The yellow circle shows the location in the coils of the maximum hoop stress. Holding the mouse temporarily over a coil in the bottom-left plot will display its properties in the lower right-hand part of the screen.

The five buttons on the upper right part of the screen are controlled by clicking with the mouse. ENTER PARAMETERS brings up a series of windows for the user to enter the parameters for a new design. OPTIMIZE brings up a series of windows for the user to start an optimization study. SAVE PARAMETERS is used to save the parameters for a design to a file. AUXILIARY OPERATIONS brings up a choice of additional calculations. EXTRACT DATA creates external ascii files of selected information.

The area on the lower right is used to display numerical values for some important coil properties.

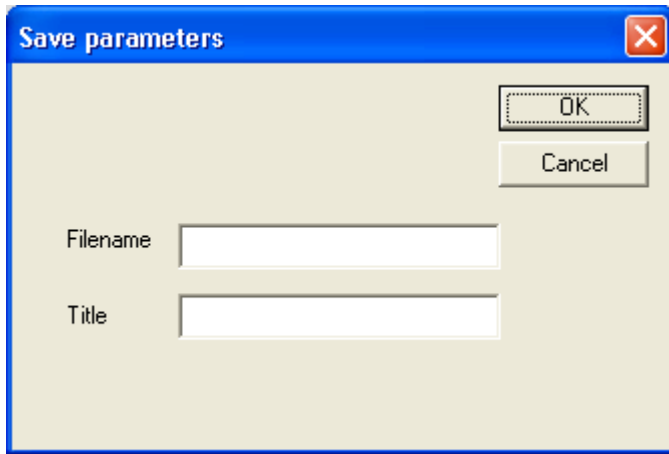
The magnet characteristics given in the lower right hand box are:

B0	maximum solenoid field on-axis
S Bdz	integral B dz along axis
Uint	total stored energy inside the conductor cross section only

If a field grid is calculated using the Auxiliary button, a fourth quantity U_{tot} appears in the lower right region, giving the total stored energy in the selected field grid.

4. Save parameters

This command is used to save the parameters for the current design.



Besides the name of the file the user can enter some descriptive information as the title.

This file can also be created offline with a text editor. The format of the file is:

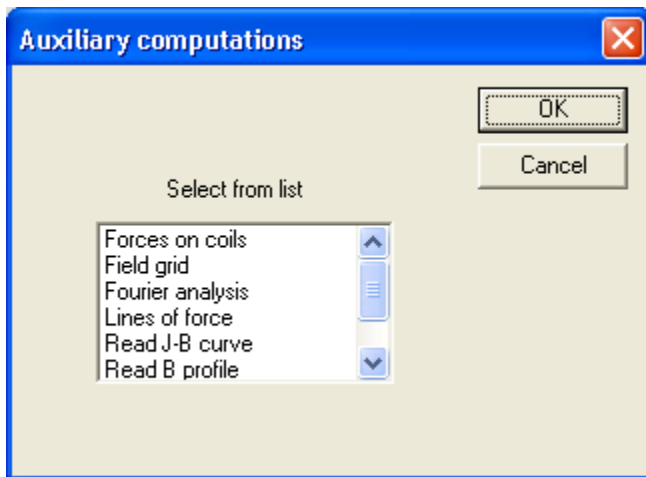
```
Title          (a80)
zmin zmax rmax  (R) lower (upper) axial limit and radial limit [cm]
ncoils          (I) number of coils {1-32}
For i=1,ncoils
  id za(i) La(i) aa(i) ta(i) Ja(i) ctype(i) fsc(i)
  where      id  (I) identifying number for user convenience
              za  (R) axial position of left edge of coil [cm]
              La  (R) axial length of coil [cm]
              aa  (R) inner radius of coil [cm]
              ta  (R) radial thickness of coil [cm]
              Ja  (R) engineering current density [A/mm2]
              ctype (A) conductor type
                  {NbTi, Nb3Sn, BSCCO, YBCOG, YBCOb, Cu, Fe, USER}
              fsc  (R) current density scaling factor for the material
```

The five defined superconductors {NbTi, Nb3Sn, BSCCO, YBCOG, YBCOb} use reference J-B curves for 4.2 K. YBCOG is YBCO tape in the “good” direction, i.e. with B in the plane of the conductor tape. YBCOb is YBCO tape in the “bad” direction, i.e. with B perpendicular to the plane of the conductor tape. A coil with USER superconductor will use a J-B curve that the user has read in using the AUXILIARY button.

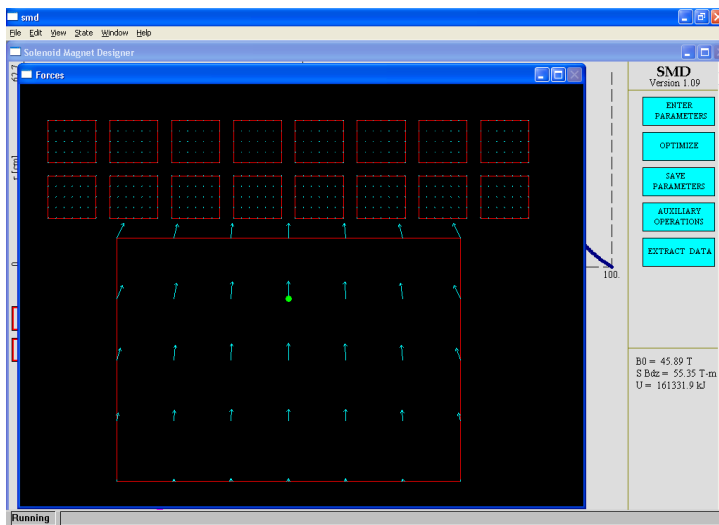
5. Auxiliary Operations

The AUXILIARY OPERATIONS button brings up the choice of the following additional calculations:

- Force distribution inside coils
- Field grid
- Fourier analysis of on-axis field
- Lines of force
- Read new $J_{\text{eng}}(B)$ curve for conductors
- Read desired on-axis magnetic field profile
- Plot difference between profile and actual B on-axis

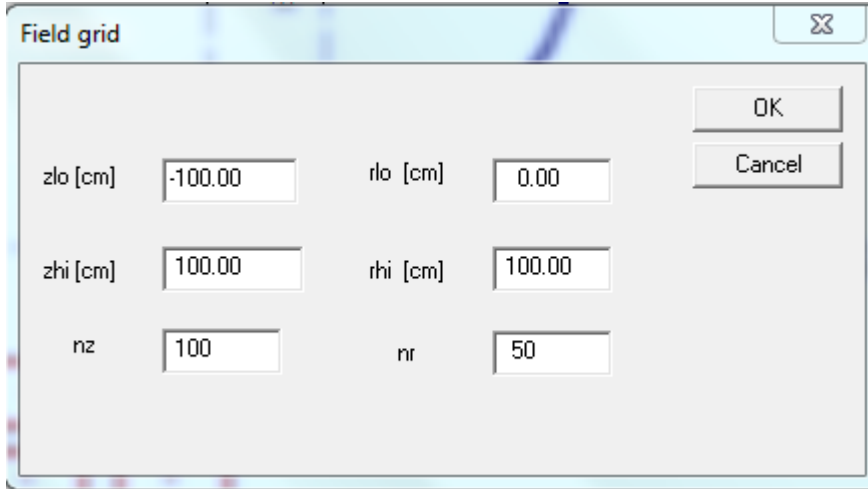


The user must select one of the items in the list and press OK. If the Auxiliary window is not visible, you can select it from the Windows menu. Here is an example of forces on the coil.



The location of the peak magnitude of the force is shown as a green circle.

If Field Grid is selected, the following dialog window appears

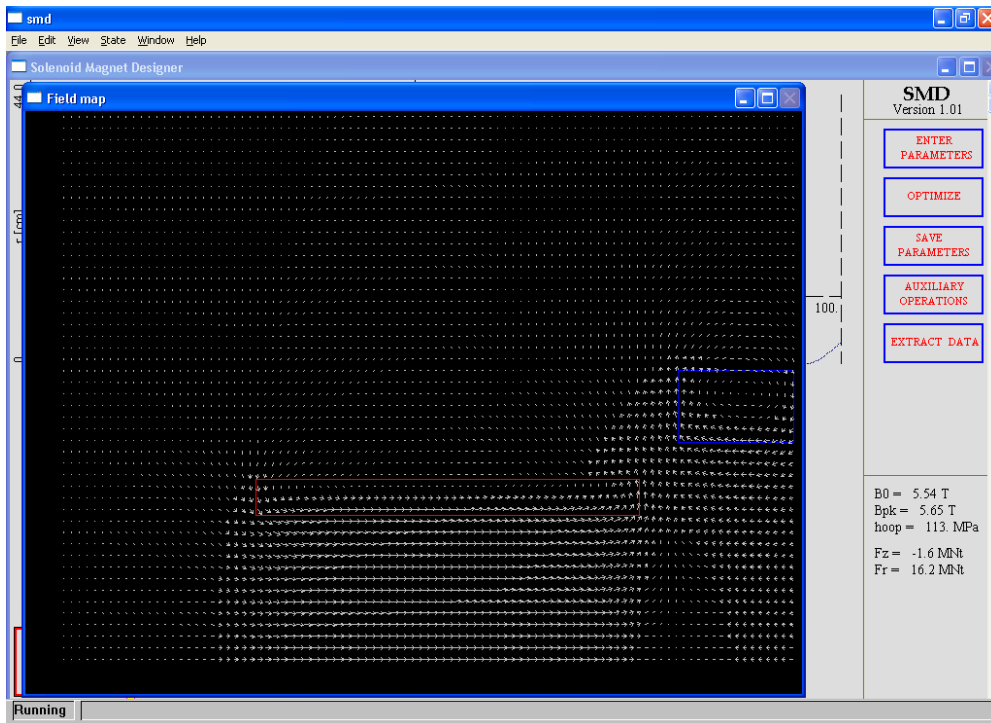


The 'Field grid' dialog window contains the following input fields:

Parameter	Value
zlo [cm]	-100.00
rlo [cm]	0.00
zhi [cm]	100.00
rhi [cm]	100.00
nz	100
nr	50

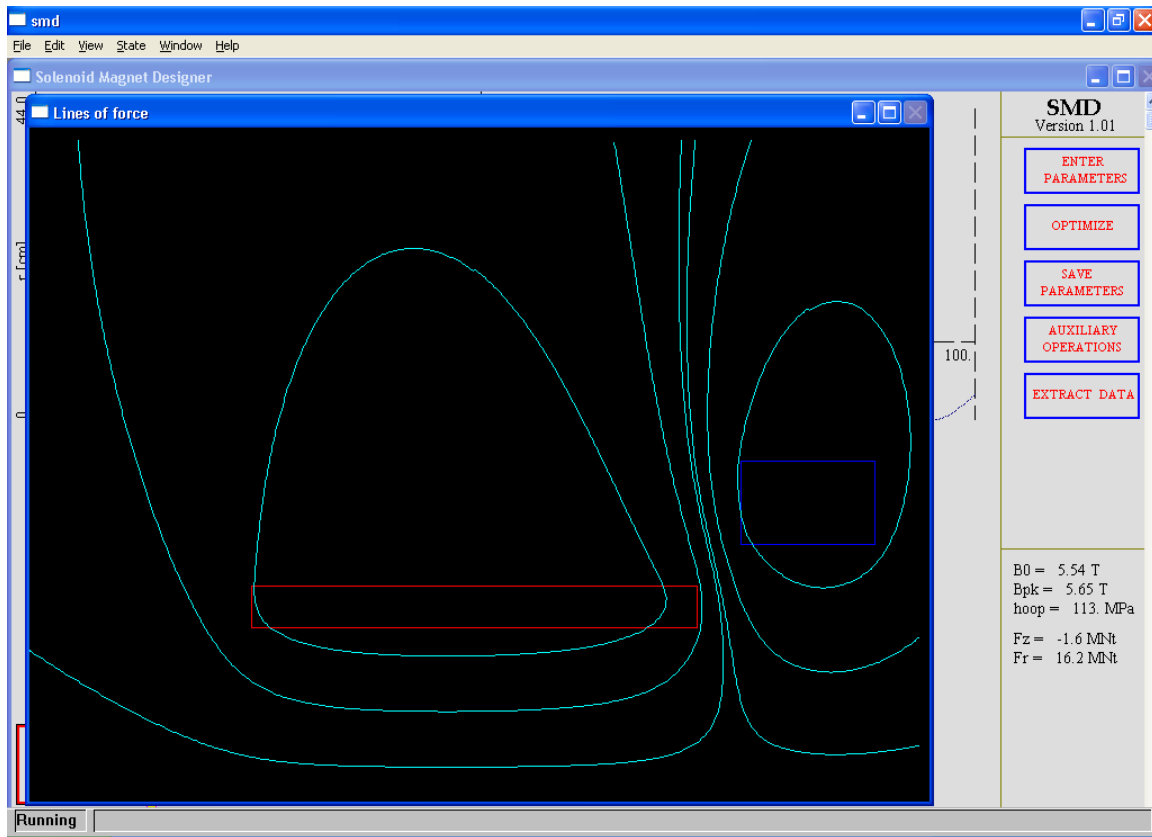
Buttons: OK, Cancel

which allows the user to define the extent of the field grid. The maximum number of z grid points is 200 and the maximum number of r grid points is 100. Here is an example of a magnetic field grid.



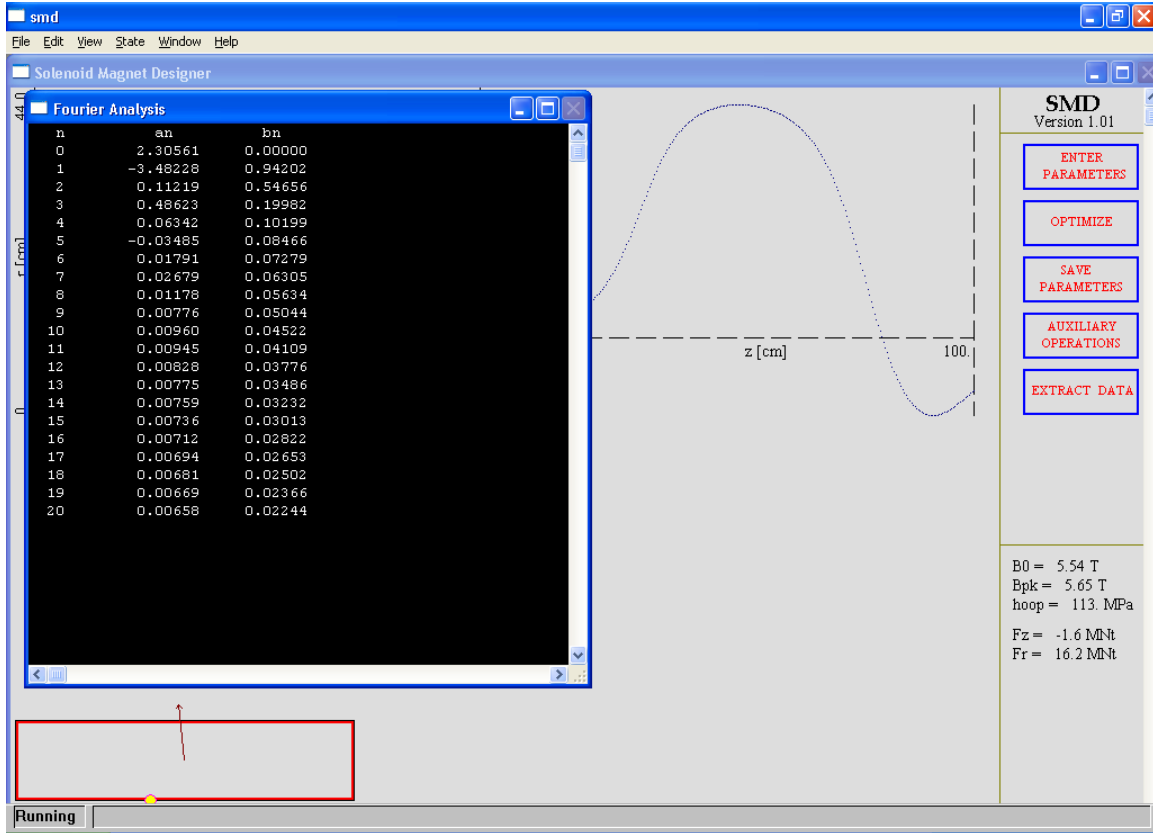
The coil positions are outlined in red and blue.

Here is an example of magnetic lines of force.



The coil positions are outlined in red and blue.

Here is an example of a Fourier analysis of the on-axis magnetic field.



The a_n coefficients are the cosine-like terms, while the b_n coefficients are the sine-like terms.

The format of the external magnetic field profile file is

```
title (a80)
npts (i) (1-50)
For i=1, npts
z [cm]      B [T]
```

The format of the external J-B curve file is

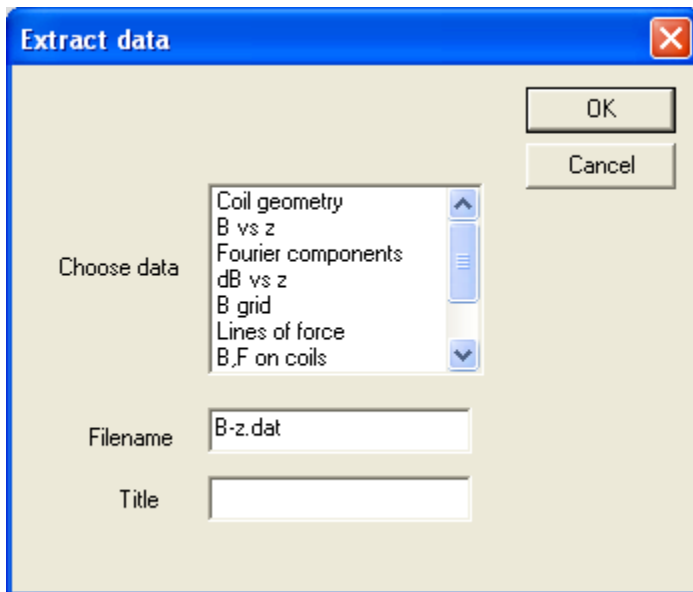
```
title (a80)
npts (i) (1-50)
For i=1, npts
B [T]      J [A/mm^2]
```

6. Extract Data

EXTRACT DATA creates external ascii files of selected information:

- Coil geometry
- B(z) on-axis
- Field & force on coils
- Map of forces
- Field grid
- Fourier coefficients
- Lines of force
- Field error from desired profile
- Internal $J_C(B)$ data

This will bring up the following window.



The user can specify the file name where the data is written and can specify up to 60 characters of “title” information at the head of the file. All available information can be written to a single file by choosing All Data.

7. Optimization

The first window controls some general properties of the optimizer.

Optimizer settings

☐ LOG file? File name

Max iterations

B at point

Bz (z,r) [T]

Br (z,r) [T]

z [cm]

r [cm]

Weights

B(z,r)

B profile

Bp at coil

B profile

Filename

Start z [cm]

End z [cm]

Optimizer method

simplex
direction set

Peak field in coil

Coil # for Bp

OK

Cancel

The progress of the optimization can be saved in an ascii log file. The optimizer builds the merit function from components. You can require a given magnetic field at a specified (z, r) location. You can require that the magnetic field match a B(z) profile read in from an external file. The optimization is done between the z limits given in the boxes. Lastly you can try to minimize the peak field in a given coil. The merit function is controlled by the weights assigned to each of these requirements. At least one weight must be non-zero. The maximum number of iterations roughly controls how long the optimizer will continue. You can choose to use the simplex or the direction set method for optimization.

After this window is closed the coil Input parameters windows appear again.

The second Input window is used to specify which parameters will be varied.

Input magnet parameters

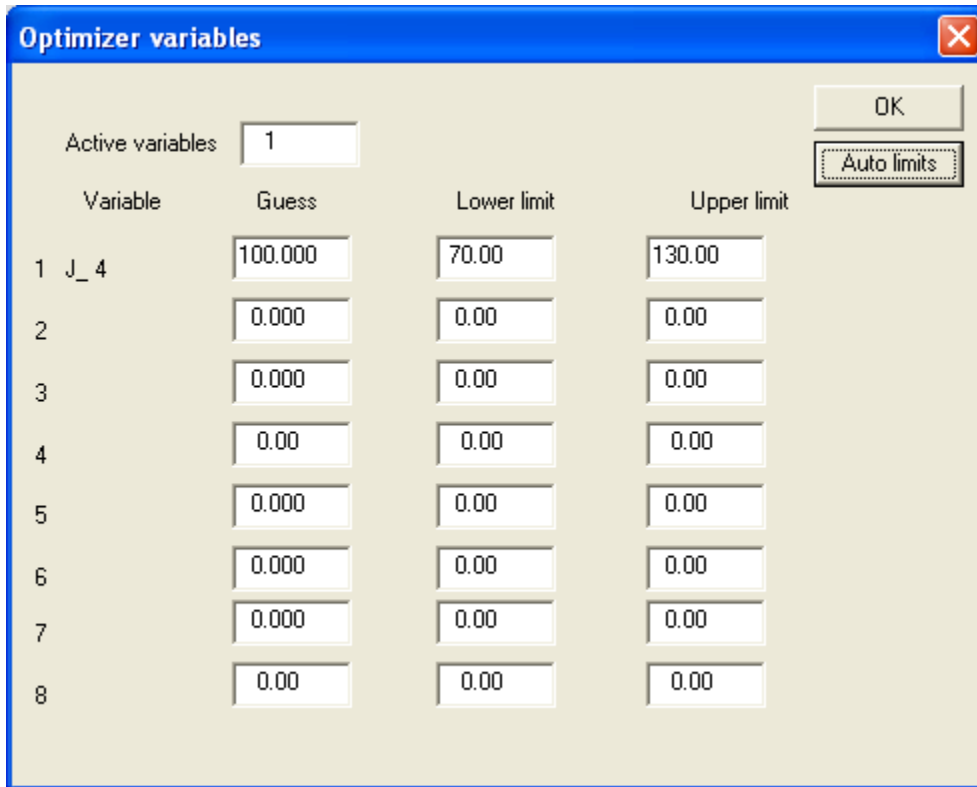
Number of coils: 18

coil #	z0 [cm]	L [cm]	a [cm]	t [cm]	J [A/mm ²]	SC material	Scale factor
1	-71.20	74.90	17.80	5.40	-991	Cu	1.00
2	-71.20	87.70	23.20	12.20	19.20	Cu	1.00
3	-71.20	107.30	35.30	13.70	-992	Cu	1.00
4	-125.30	178.10	63.60	64.20	23.54	Nb3Sn	1.00
5	62.80	72.90	68.60	32.50	25.48	Nb3Sn	1.00
6	145.70	99.90	77.60	21.20	29.73	Nb3Sn	1.00
7	255.60	155.00	77.60	10.70	38.26	Nb3Sn	1.00
8	420.60	185.90	77.60	6.56	42.84	Nb3Sn	1.00

Use tags -991 to -998 to specify optimizer variables

The user enters the tags from -991 to -998 to indicate which parameters to vary in the optimization. The example shown here has two variables: the current densities of the first and third coils.

At this point a second optimizer window appears where the user can specify an initial guess and lower and upper limits for each of the optimizer variables.

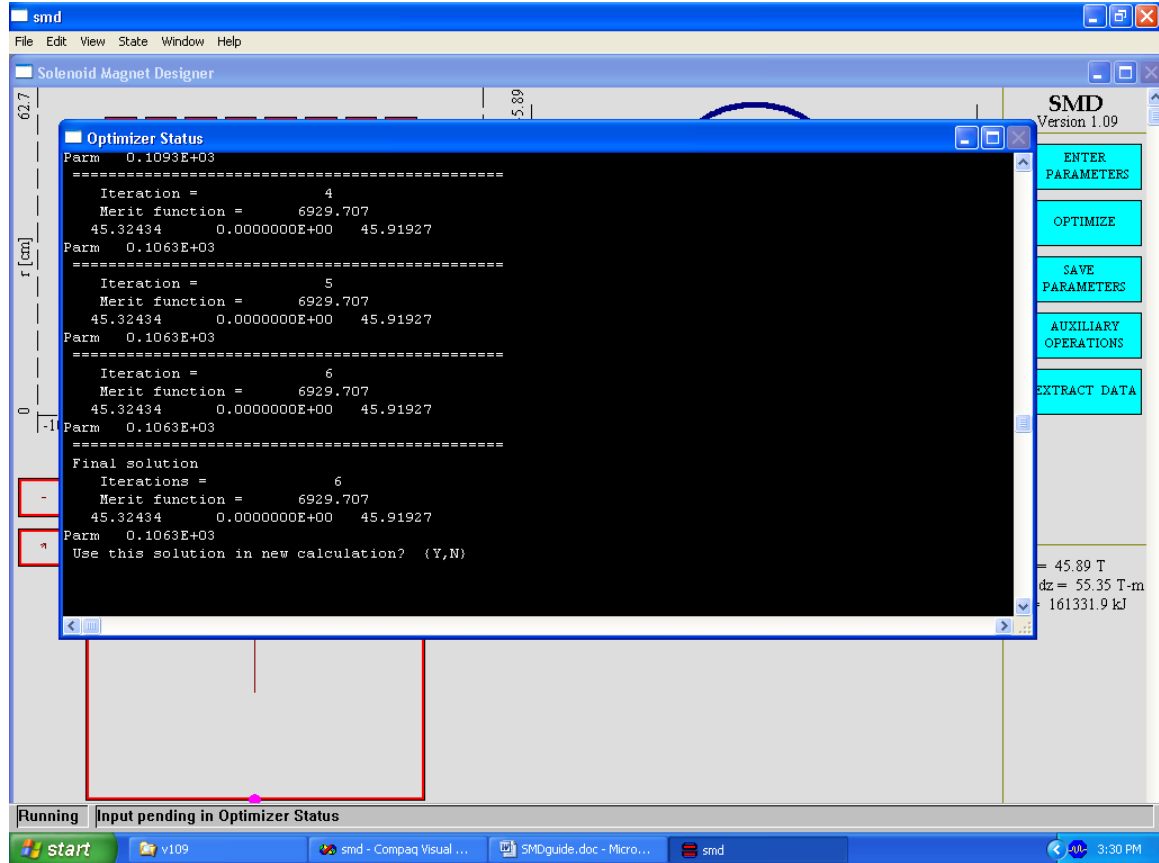


The image shows a software window titled "Optimizer variables" with a standard Windows-style title bar (blue with a close button). Inside the window, there is a section for "Active variables" with a text box containing the number "1". To the right of this section are two buttons: "OK" and "Auto limits". Below this is a table with four columns: "Variable", "Guess", "Lower limit", and "Upper limit". The table contains eight rows of input fields. The first row is labeled "1 J_4" and has values 100.000, 70.00, and 130.00. The remaining seven rows are labeled 2 through 8 and all have default values of 0.000, 0.00, and 0.00.

Variable	Guess	Lower limit	Upper limit
1 J_4	100.000	70.00	130.00
2	0.000	0.00	0.00
3	0.000	0.00	0.00
4	0.00	0.00	0.00
5	0.000	0.00	0.00
6	0.000	0.00	0.00
7	0.000	0.00	0.00
8	0.00	0.00	0.00

The user must enter an initial guess and lower and upper limits for each of the active variables. Clicking on the Auto Limits button will preset the limits automatically to $\pm 30\%$ of the initial value.

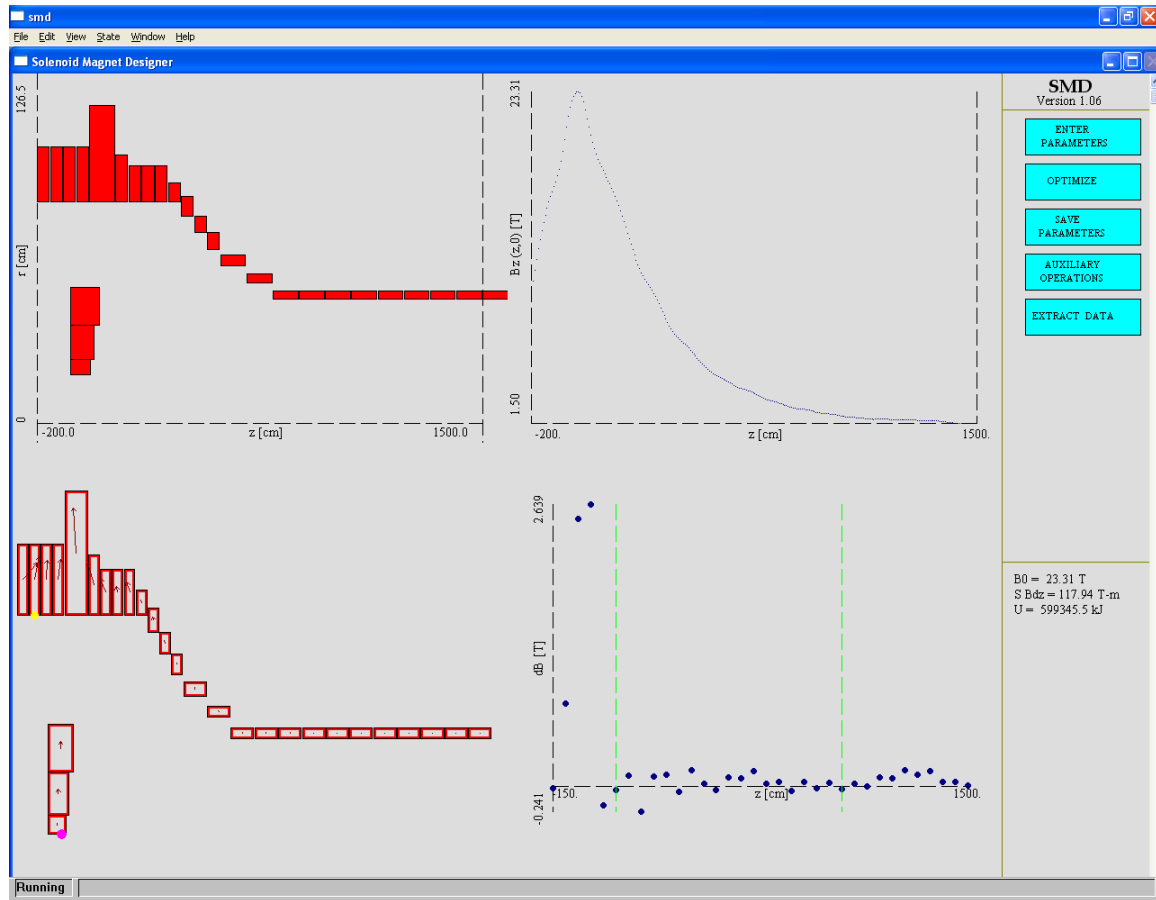
Once the optimization begins the progress is displayed in another window.



The window shows the iteration number, the value of the merit function, and the values of $B_z(z,r)$, $B_r(z,r)$ and the peak field in Tesla in the specified coil. The last row shows the values of the selected fit parameters.

At completion the user must type Y to replace the current solution with the optimizer results, or N to ignore it.

If the user is fitting the on-axis field to a desired profile the error field is displayed in the lower right-hand plot.



The vertical green lines show the current z limits for the optimization.